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Atmospheric & Terrain Effects on Acoustic Propagation

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ABSTRACT

Three computer models have been configured to give predictions under a range of atmospheric and terrain conditions which have allowed comparisons with measurements.

A New Parabolic Equation (PE) model, (HIPEDEM) which uses the robust Crank Nicholson (CN) algorithm and which includes novel procedures for treating the ground and upper atmospheric boundaries has been developed together with a new turbulent atmosphere front end processor which can be coupled to the high atmosphere PE to give turbulent atmosphere predictions.

A new generalised terrain PE model (GT-PE) has been developed which is capable of predictions over any smooth two dimensional terrain profile in the presence of a moving atmosphere.

A feasibility study on the Split Step high speed PE has also been completed and a tutorial code for testing it has been written. Some interesting insights into the operational requirements of the Greens Function PE (GF-PE) have been gained.

Key Words

Atmospheric effects, terrain effects, Acoustic Propagation, Parabolic Equation Model, Acoustic prediction, isoturbulent model.

STATEMENT OF PROBLEMS STUDIED

Scope

To extend the utilization of acoustic assessment and prediction models to include atmospheric and terrain features that effect propagation and more can operate on a PC type computer. To more accurately describe the acoustic and interacting meteorological phenomena using a parabolic equation which will permit the inclusion of range dependent atmospheric and ground impedance effects. To base the prediction model on a wide angle Parabolic Equation (PE) algorithm; the algorithm to use the robust Crank Nicholson procedure.

Objectives

To determine the atmospheric and terrain effects on the propagation of low frequency impulse noise over long distances and under any meteorological conditions. The models will include effects of turbulence and ground impedance from relatively absorbent surfaces eg. soft sandy soil to highly reflective eg. water. They will run on high level PC computer systems. Verification will be by comparison with relevant acoustic databases.

1. INTRODUCTION

The outstanding work required in the original programme was the completion of the feasibility study on the Split Step high speed PE. Time has not permitted us to do further work on the Padé method. However a considerable amount of work has been completed on the Green's Function PE (GF-PE).

The initial work on the standard split step method (without ground) has now been incorporated in the tutorial paper[1]. Further work on the mathematical treatment of the GF-PE (done in close collaboration with Gilbert and Di) has also been incorporated in the above paper.

Original GF-PE code, written by Di, has now been modified to allow met input and graphical outputs. In addition our own tutorial code has now been written for testing the GF-PE. Some interesting insights into the operational requirements of the GF-PE have been gained.

The original high atmosphere CN-PE model described earlier[2] has now had a turbulent atmosphere front end processor added to permit predictions through an isoturbulent atmosphere.

The Generalised Terrain PE program also described in an earlier report[3] has now been configured in a form allowing met profiles to be used. This completes the proposed work on this model.

2. TUTORIAL PAPER ON THE GF-PE MODEL

A detailed tutorial paper on the GF-PE has been written in close collaboration with Gilbert and Di at ARL, Penn State University[1]. The paper, although not yet complete, covers a substantial part of the programme of work required for this contract on the feasibility of the GF-PE.

The paper presents a free air (without ground) derivation of the split step PE. This is then modified to include atmospheric refraction from met effects. A detailed derivation of the Green's function form of the PE is then given which permits the inclusion of the ground boundary condition within the Green's function formulation. At this point the field solution is in the form of a difficult contour integral which is manipulated with a sequence of integration variable changes. This allows the "specular" and "surface wave" poles to be exposed and a final formulation of the integrals which can be evaluated with FFT's.

The paper describes the methods for setting up a working algorithm and gives specific suggestions for using the algorithm operationally (see below).

3. FORTRAN GF-PE TEST PROGRAMS

3.1 Tutorial Program

A "tutorial" program for implementation of the GF-PE has been written primarily to facilitate understanding of the procedure. The program includes extensive diagnostic facilities with graphical outputs of all terms evaluated prior to the main range loop. This implementation is not intended to be very efficient and does not give the full high speeds possible with this method.

3.2 High Speed "Optimised" Program

This is based on Di's original version using a very efficient implementation which requires only 2 (double length) FFT's per range step. Normally 4 FFT's are needed because the GF-PE integrals contain a direct and reflected term so that 2 FFT's are needed to transform into wavenumber space and 2 to return to z (vertical-height) space. The 2 FFT procedure makes use of the storage used by the FFT algorithm to allow the use of a double length function in place of two single length function in both z and k spaces. The program also has a very efficient numerical integration procedure for the surface wave term.

The program has been given a number of additional subroutines and code to allow real met data to be imported. This data is obtained from the LARRI met processor which converts measured RADIOSONDE or MESOSCALE raw met data into a "realistically" smoothed form suitable for calculation of the sound speed profile function, c(z), required for the PE models.

A full colour-fill contour output has been added to the program to allow presentation of the solutions for a full vertical azimuthal plane. This has a similar format to that used for a CN-PE. Because the GF-PE gives solutions along a vertical at widely separated range steps (typically $\Delta r = 20\lambda$) we must use a 2D interpolation to allow presentation of the contours. The procedure used employs a liner interpolation algorithm which does allow "coarse" contours to be obtained. (Gilbert has suggested a more sophisticated k space interpolation). In addition to the colour fill contour plots the program presents attenuations re 100m as a function of horizontal distance from the source at a preselected height, z_r.

A second version of the optimised program has been coupled to a cut down version of our CN-PE so that the graphical outputs of the two programs can be compared on one screen. This has proved to be extremely useful in evaluating the error in the GF-PE's predictions.

3.3 Operational Requirements for Successful Use of the GF-PE Program

Unlike the CN-PE which is extremely robust and very accurate (provided its mesh is smaller than $\lambda/5$), the GF-PE can give incorrect results if it is not set up correctly. For our initial testing we selected the following parameters

source height	$z_s = 2\text{m}$
receiver height	$z_r = 2\text{m}$
range step	$\Delta r = 20\lambda$ (m)
vertical step	$\Delta z = \lambda/5$ (m)
frequency	$f = 50$ Hz
range	$r_{max} = 4000\text{m}$
ground impedance	$z_b = (20.0, 20.0)\ \rho_0 c$ units

For the CN-PE stage Δr was set equal to Δz. The test met conditions were

linear positive gradient	$g = 0.02, 0.05, 1$
linear negative gradient	$g = -0.02, -0.05, 1$
logarithmic profile	$a = 01.5, 1.0$

For the linear cases $c(z) = c_0 + gz$

and for the log cases $c(z) = a\ \ell n\ z/0.1$

The tests showed up errors in the GF-PE which became large

(1) when $\Delta r < 10\lambda$

(2) when $g > 0.05$ for the linear gradients

(3) when $| z_b | > 50.0$

Discussions with Gilbert identified problem (3) as a consequence of incorrect calculation of the surface wave component. In the case of a very hard boundary the surface wave integral must be performed over a much larger height range to yield the expected small value. The easiest solution to this problem turns out to be simply to discard the surface wave calculation and set the surface wave contribution to zero when $| z_b | > 10.0 \rho_0 c$.

The errors (1) and (2) results from the requirement that slopes of characteristic lines (rays) over a range step must be small for the GF-PE to be valid.

Even in the still air case errors of a few dB arise at distances greater than 2 km and these are still being investigated by ourselves and Gilbert and Di.

4. WORK ON THE HIGH ATMOSPHERE PE WITH A TURBULENT FRONT END

The development work on the CN-PE has been described in detail in the interim report USARL/01S[2]. As part of the requirements in the programme of work for this contract we undertook the incorporation of a turbulent atmosphere front end processor which would allow PE predictions in the presence of a turbulent atmosphere.

The turbulent atmosphere algorithm is based on a procedure originally developed as part of our programme of work for the UK MOD (Directorate of Health and Safety). The turbulent realisation is obtained by a synthesis algorithm which assumes

(a) that the turbulence is homogeneous (isoturbulence)
(b) that the turbulent spectrum is Gaussian.

A precise but unnecessarily complicated procedure was initially set up to give the turbulent realisation on a mesh whose size was set up according to the turbulent length scale, ℓ, we have shown however that for use with a PE the PE mesh dimension can be used directly for the turbulent realisation. The new turbulent processor incorporates two novel features

(a) an imposed z dependent function applied to the output realisation

(b) an algorithm for determination of ℓ making due allowance for the PE mesh size/frequency.

Multiple realisation solutions are possible with the program though the full computation of all turbulent realisations with their PE solutions is very time consuming.

5. GENERALISED TERRAIN PE MODEL

This model has been described in detail in the interim report USARL/02S[3]. A full implementation of the algorithm, based on our original published description of the method[5], has been completed and predictions have now been obtained with the program for a test terrain profile. More recently the program has been modified to allow true met profiles to be input. The profiles are taken at a location a small distance from the hill preferably over flat ground. A simple procedure is used to "compress" the profiles as we move over the hill. The range dependent profiles are used directly with the GT-PE in a similar manner to the way the turbulent atmospheric realisation was used in the CN-PE.

6. CONCLUDING SUMMARY

The following work has been completed during this contract:

1. The development of a deep atmosphere long range PE model capable of taking raw meteorological data as input. The program has a user friendly interface.

2. The addition of a turbulent atmosphere front-end program to the above PE allowing predictions for a single realisation of a turbulent atmosphere.

3. The development of a generalised terrain PE model capable of predictions over any smooth 2D terrain profile.

4. An examination of the new high speed GF-PE model with particular reference to its feasibility for long range predictions.

All the above models are developments of original codes initially produced for the UK Ministry of Defence.

6.1 Validation Studies

1. A number of separate validations of the HI-PE model have been carried out against trials data obtained in a wide range of meteorological conditions. In a recent publication[6] comparisons of HI-PE predictions with trials measurements are presented for some downward refracting cases.

2. The turbulent models predictions have been validated for selected upwind cases against trials data. In these cases turbulent effects are at their greatest.

3. To date the terrain PE's predictions has only been validated for still air conditions by checking them against predictions given by a 'barrier' procedure.

4. The GF-PE's predictions are being checked by comparing them with those from the CN-PE.

7. RECOMMENDATIONS FOR FUTURE WORK

1. The HI-PE requires a means of speeding it up by between 10 and 100 times its present speed. This may turn out to be possible only with purpose built hardware.

2a. Investigation of the importance of using a 2 scale turbulence spectrum for setting up a more realistic atmospheric realisation.

2b. Investigation of a means of generating a turbulent atmospheric realisation based on a variable turbulence scale.

3. Examination of the importance of back scattered components to the accuracy of the GT-PE for terrain profiles with steep sections.

4. Completion of the examination of the GF-PE and the determination of its feasibility for long range propagation. This will require isolation of the causes of numerical error which have so far been discussed.

8. LITERATURE CITED

1. K Gilbert, X Di, M West, R A Sack. A Tutorial on the Generalised Split Step Parabolic Equation Method for Fast Computation of Atmospheric Sound Fields. In preparation. For submission to Applied Acoustics, 1995.

2. Atmospheric and Terrain Effects on Acoustic Propagation. University of Salford Report USARL/01S, February 1994. (Contract DAJA45-93-C-033, 1st Interim Report).

3. Atmospheric and Terrain Effects on Acoustic Propagation. University of Salford Report USARL/02S dated May 1994. (Contract DAJA45-93-C-033, 2nd Interim Report).

4. M West and R A Sack. A Two Dimensional Model of Isotropic Atmospheric Turbulence Employing the Method of Closure. Paper BNP42. MOD (D.Def H & S) submitted August 1991 (re-issued with amendments October 1994).

5. R A Sack and M West. A Parabolic Equation for Sound Propagation in Two Dimensions over Any Smooth Terrain Profile: The Generalised Terrain Parabolic Equation (GT-PE). Applied Acoustics 1994 (In press).

6. M West, J Turton and I D Todd. On the Accuracy of Ray Tube Model Predictions for Realistic Meteorological Conditions. Applied Acoustics 42 (1994) 277-289.

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